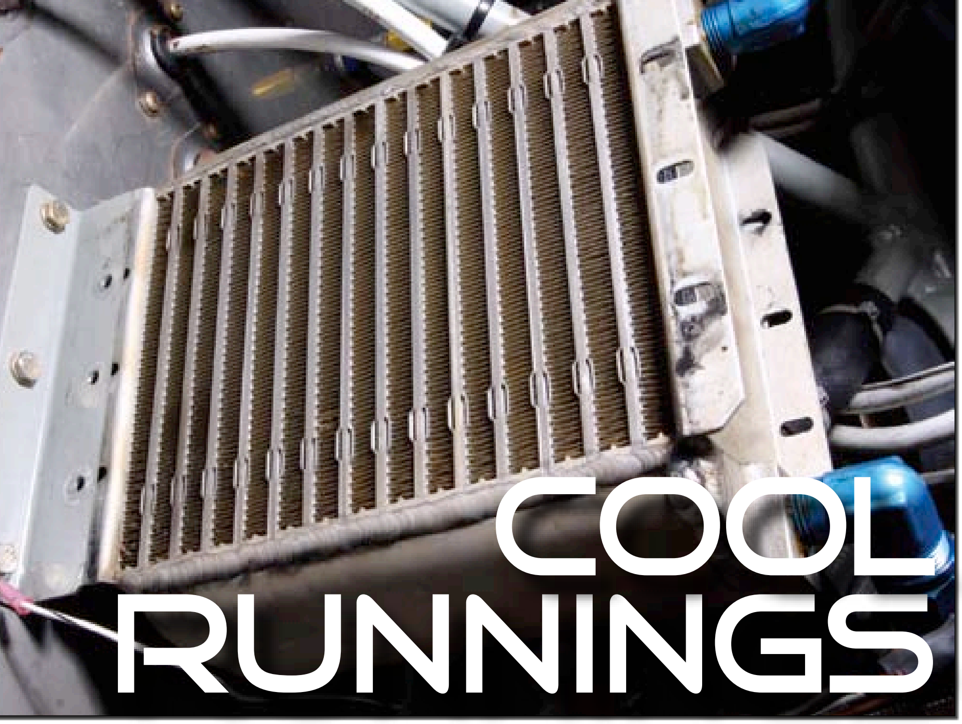


COOL RUNNINGS

There's more to maintaining ideal oil temperature than choosing the biggest oil cooler you can find.

BY NORM ELLIS

Among the various homebuilt-project maladies, high engine temperatures rate near the top of the list. And, more than anything, it's greater-than-desired oil temps that cause builders to wonder what they did wrong, and how to fix the problem. Take a quick poll, and you might believe that sizing and mounting an oil cooler are more art than science; sometimes builders get lucky, sometimes they don't.

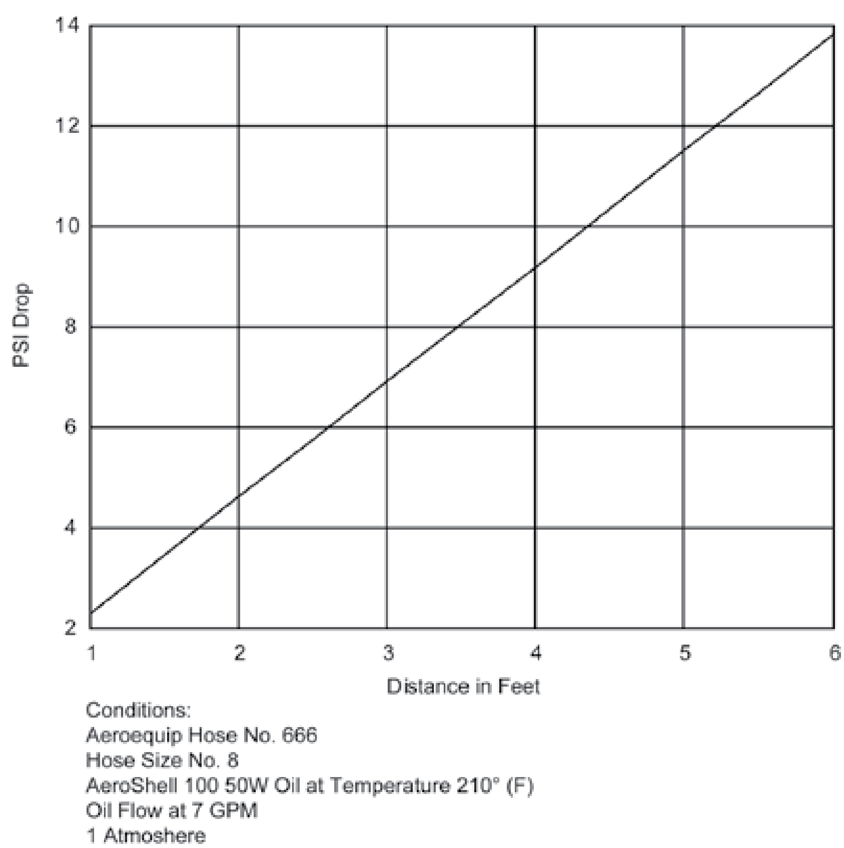
In researching the subject of oil coolers in general, I discovered that a lot of data is either old or missing, and that, it appears to me, many airframe manufacturers (certified and not) take the cut-and-try approach to sizing and fitting oil coolers. Using real data and some math, we can determine, generally, how large an oil cooler any engine requires; see the sidebar "Let's Do the Math" on Page 42. But that's just half of the equation, so to speak. The second part is the installation itself.

For an airframe manufacturer (and this includes kit makers), the oil cooler may well be the last consideration in the entire engine-cooling package. An airframer typically wants to start with the smallest (lightest) and cheapest cooler that will do the job. Sometimes, this results in a marginal system. Cessna

Your oil cooler is a key component to keeping your engine happy. Be sure it's the right one!

Fittings and hose size are important. Right-angle fittings, like these, can contribute to flow restrictions.

Figure 1.

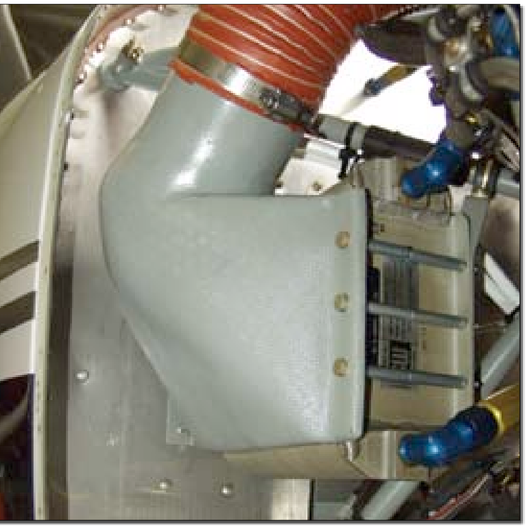


Photos: Marc Cook

Turbo 210 owners, for example, are accustomed to seeing the oil-temp gauge hugging the redline in a summertime climb. But you, as the manufacturer of your kit aircraft, can be smarter, choosing the right cooler and mounting it properly because the small incremental costs of the effort are not bloated by manufacturing numbers; instead, it's a comparatively tiny investment to keep your larger investment (the engine, that is) happy.

Where Should It Go?

The most familiar place for an oil cooler is in the engine compartment. There are exceptions, of course, but for reasons of reduced install weight, minimizing the length of the oil lines and various other considerations, the practical solution is to keep the cooler close to the engine, even if a remote location might cool the engine more effectively. For Lycoming installations, which typically employ a remote cooler, the most common locations are the firewall, behind the vertical baffling behind the engine, or below/beside the engine. Many Continental designs have integrated coolers, either ahead of the cylinder row or behind it; for these installations, there's not much



For optimum efficiency, the cooler's inlet duct should be as straight as possible. But sometimes compromises have to be made.

Let's Do the Math

An oil cooler is a radiator. Instead of water, oil cools 40% of the engine, and air cools the rest of the engine and the oil. Air-cooled engines dissipate waste heat directly through the cylinder head and walls to the outside air, and also through the engine oil.

After extensive research, I was able to gather all the information that you will ever need to know about sizing oil coolers for aircraft engines in light aircraft. We will use the Lycoming IO-360-A1B6D, a 200-horsepower, angle-valve four-cylinder engine, as our example. Don't get hung up on that specific engine. All air-cooled engines drive heat into the oil, but the main difference is how much. Horsepower is a good indicator, but there are other variables. Is the engine turbocharged? (That puts more heat into the oil than the gain in horsepower would suggest.) Does the engine have piston "oil squirts" as a means of reducing cylinder-head temps (CHT)? This feature places a much greater heat load on the oil than in engines without them, and it must be accounted for.

Manufacturer Requirements

Exactly what is the engine manufacturer's requirement? I recommend requesting an engine detail specification sheet from the manufacturer rather than relying on what is printed in the aircraft catalog or cross reference information. According to Lycoming's documentation (dated August 4, 1977): "Provision is made for use of a full flow oil cooler with this engine. Oil flow through the cooler system will be approximately 7 gallons per minute and heat rejection will not exceed 750 Btu per minute. Note: The oil cooler must be capable of withstanding continuous pressure of 150 psi. A thermostatic oil cooler bypass valve is supplied as standard equipment. It limits pressure drop between cooler connection to 75±15 psi and closes at 185° F oil temperature to put all engine oil flow thru the cooler." Another document, the *Lycoming Aircraft Engine Installation Manual*, published in 1940, reads: "In order to maintain engine oil temperature within the limits required by the engine and the characteristic of the lubricant, suitable means should be provided for cooling the oil. The oil cooler must be designed for adequate warm-up and anti-congealing performance, and be protected against surge pressure." Physics hasn't changed in the decades since then. In a section titled "Oil Cooler Design Factors," the formulas provided are the same ones that are used here.

Sizing the Thing

Finding the right size oil cooler requires solving for the following: oil mass flow, (lb/min); heat transfer, worst case (Btu/min); temperature difference (Btu/min).

Solving for the oil mass flow rate, or the amount of oil flowing thought a point in the system per unit of time relative to the volumetric flow in cubic feet per minute, and density (ρ) in pounds per cubic feet, is the easy part. The resulting equation for oil mass flow rate is measured in pounds-mass per minute.

The information in Table 1 must be known to solve this and other equations that will be

Table 1: Necessary Information for Problem Solving

Description	Properties
Oil flow from the engine manufacturer in gpm	7 gpm
Oil temperature into oil cooler = T1 (°F)*	230° F
Oil temperature out of oil cooler = T2 (°F)**	190° F
Specific heat of the oil = Cp (Btu/lb-°F)***	0.5205 Btu/lb-°F at 230° F
Density of oil = ρ (lb/Ft^3)***	51.8 lb/Ft^3

Notes: *This a theoretical oil temperature from the example engine. **This is the desired oil temperature returning to the engine. ***Oil used is Aeroshell W100 50w (SAE 50 weight).

used for sizing an oil cooler.

The formula to solve oil mass flow rate is:

Oil mass flow rate (lb/min) = (gpm) x (231 in^3/gal) x (1 ft^3/1728 in^3) x *p*

Inputting the above information into the formula, oil mass flow rate for this engine is:

48.473 lb/min = (7 gpm) x (231 in^3/gal) x (1 ft^3/1728 in^3) x (51.8 lb/ft^3)

Solving for Heat Transfer

Next, we'll solve for heat transfer (worst case). The problem with an oil cooler is based on the physics heat exchange equation of heat lost = heat gained. Heat exchange occurs when hot substances are mixed with cool substances.

The formula for heat transfer is: Q = Cp w ΔT

In this equation:

Q = heat lost or heat gain (Btu/min)

Cp = the specific heat of the substance (Btu/lb-°F)

w = mass flow rate of oil (lb/min)

ΔT = differential temperature of T1–T2 (°F)

Writing the formula out with the required information now becomes:

Q Btu/min = (Btu/lb-°F) x (lb/min) x (T1 - T2)

Inputting the information from above into the heat transfer formula, the heat rejection for this engine is:

1009.20 8 Btu/min = (0.5205 Btu/lb- °F) x (48.473 lb/min) x (230° F - 190° F)

Next, calculate the inlet temperature difference (ITD) Btu/min for the performance chart for the oil cooler capability. Stewart Warner uses 100° F for heat rejection Btu/min chart scale. This calculation is simple:

Q/ITD = (Btu/min) x 100/temp oil in - temp air in

Again by inputting the information from above into the inlet temperature difference (ITD) Btu/min formula the Q/ITD Btu/min for this engine is:

672.8 @100° F Btu/min = (1009.208 Btu/min x 100/(230° F - 80° F)

The Result of Our Calculations

The oil cooler requirement for this engine is 48.473 lb/min (rounded off to 50 lb/min) oil mass flow, and 672.8 @100° F Btu/min (rounded off to 673); however, it would be just as easy to say 670 @100° F Btu/min and not lose any sleep over 3 @100° F Btu/min.

Inline dual Stewart Warner oil coolers would have the same oil mass flow. Theoretically, dividing the 673 @100° F Btu/min in half would now be 336.5 @100° F Btu/min heat rejection.

Table 2 lists Stewart Warner oil coolers that could possibly be used under the Lycoming requirements so far. Only two oil coolers meet the required "one oil cooler for heat rejection" requirement. Note that some of Stewart Warner's oil coolers are single air pass, single oil pass, and some are single air pass, dual oil pass. The difference is that the dual oil pass oil cooler generally has better performance. Heat rejection is better, but oil pressure drop is higher.

In my opinion, the best selection for this requirement would be dual 8406R oil coolers. In addition to the fact that the 8406R is smaller and weighs less than the rest of the Stewart Warner line, performance is compatible with the installation requirements.

The use of one or two oil coolers really depends on the room in the engine compartment. Using one oil cooler can be great if there is lots of room for a big one. However, bigger is not always better.

Two oil coolers divide the heat rejection between them, making it easier to cool the oil cooler due to size and the increased length of time the oil is cooled before returning to the engine. The more time the oil is away from the engine, the more Btus it will take to heat and keep the oil hot. The cooling from two oil coolers is also more efficient than one, and it is easier to find the right duct size.

—N.E.

Table 2: Stewart Warner Oil Coolers for Example Engine

Part No.	No. of Passes	No. Required
8406R	Single	2
8432R & S	Dual	2
10599R	Single	2
10610R	Single	2
10611R & S	Single	2
10614R, S & T	Single	2
10865B	Single	1
10877A	Single	2
10886A	Single	1

SCAT hose is actually not the best kind of duct, but it offers the greatest installation flexibility.

a builder can do except to ensure the cooler receives sufficient airflow and has an unobstructed cooling-air exit path.

Mounting the cooler ahead of the engine, in the path of the cylinder-cooling flow, will influence cylinder-head temperatures (CHT) because the cooler consumes some of the air meant for the cylinders, which results in a pressure drop in the inlet side of the cooling cavity. In addition, while it would seem that mounting a cooler behind the cylinders would subject it to hotter air, that's not the case. Cooling air flowing over the cylinder (in a conventional tractor application) doesn't pick up appreciable heat before reaching the oil cooler.

There are structural issues as well. An oil cooler mounted directly to the engine is subject to the engine's vibration. Mounting the cooler to the baffling will add loads there; it's important to reinforce the baffling around the oil cooler to prevent cracks and outright failures. While Experimental aircraft designers and builders are not subject to it, FAR Part 23.1023 states: "Each oil radiator and its supporting structures must be able to withstand the vibration, inertia, and oil pressure loads to which it would be subjected in operation."

While looking at your mounting scheme, consider this issue as well: The total oil pressure drop in the oil-line hoses, fittings and oil coolers must meet the engine manufacturer's requirements. When installing the oil lines refer to AC 43.13-1B for proper guidance. Avoid restrictions to the oil flow that may cause an extreme load on the engine. Keep the oil cooler(s) and oil-cooler hose lines away from any hot surfaces.

Hoses & Things

Here is another concern of which to be aware: hose size and length. The size of the oil-line hose does not change the oil flow in the oil cooler. However, two things do happen when using, for example, a No. 6 compared to a No. 8 oil-line hose: No. 6 oil-line hose will have a 26.6% pressure drop compared to No. 8 oil-line hose from 1 to 4 feet. And No. 6 oil-line hose will have a 58.6% increase of velocity (ft/sec) compared to a No. 8. Cooler choice will dictate which size of hose you will use, but this effect is worth keeping in mind.

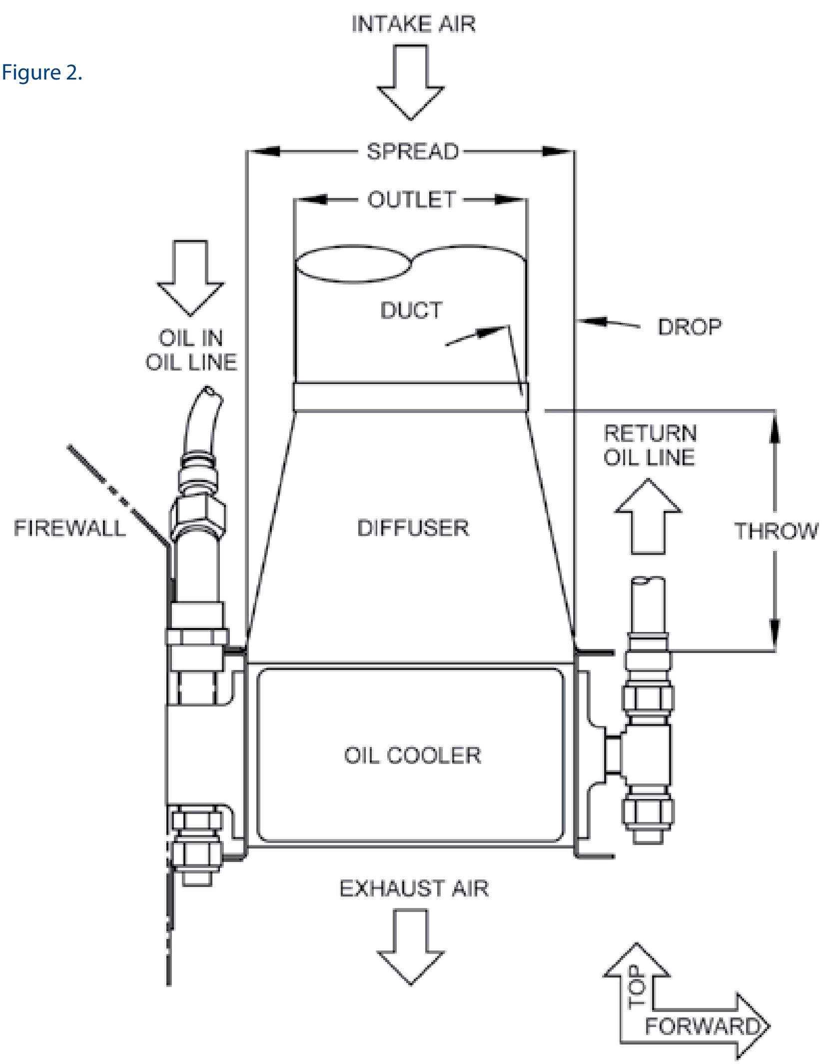
Hoses should be kept as short as possible. You will notice the pressure drop increase with the length of oil hose line. Referring to the Stewart Warner Performance Chart in Figure 1 (Page 41), and using the oil mass flow of 50lb/min at 235° F, oil temp gives a 4.7 psi drop for one oil cooler.

Duct or Scoop?

For a builder, determining how much air the oil cooler requires is a difficult assignment. How much air is entering the duct from the slipstream is unknown without testing, but as a baseline expect a 25% drop from indicated airspeed for an external duct.

The next decision, if considering an external air source—that is, if you're not taking the oil-cooler air from the back baffle or elsewhere inside the engine cooling cavity—is NACA duct or a scoop? The advantage of the NACA duct is that it requires only a small section of air from the airflow. The NACA duct enlarges and slows the air to present a smooth, low-speed, high-pressure

Figure 2.



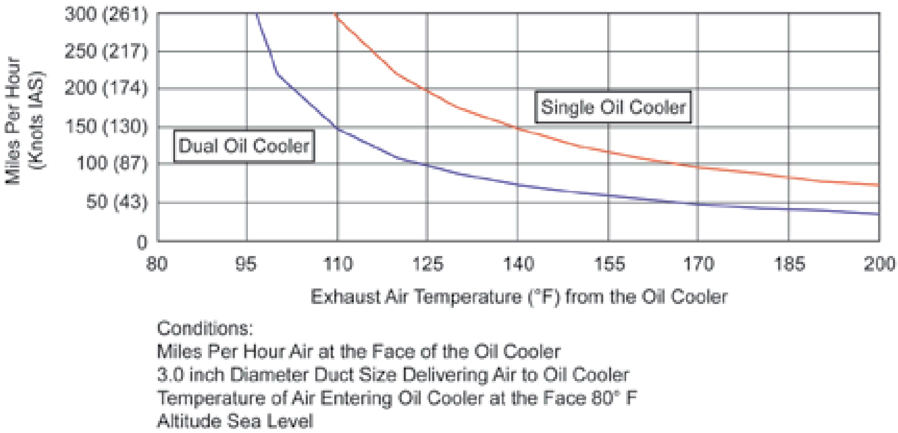


Figure 3.

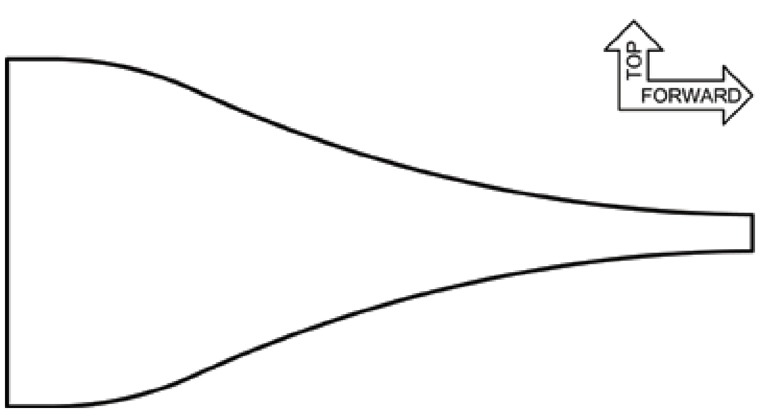
flow into the duct without disturbing the boundary layer, which would produce a significant amount of turbulence and associated drag. This provides very little disturbance to the external airflow with less drag than the scoop.

The NACA duct is best located on the forward surface where the air is being pushed aside by the expanding width of the body. The boundary layer is thin, compressed and attached to the surface. Areas to avoid when installing a NACA duct: turbulent flow area and downstream of any drag protrusions into the boundary layer.

The duct provides a transition for the air mass flow from the NACA duct to the diffuser. There are two types of ducts: round or square. Round tubing such as SCAT or SCEET is less expensive and easier to install than square or rectangular ducting. Rectangular ducting has a greater cross-sectional area for less friction or airflow resistance than SCAT tubing. For example a 4x4-inch rectangular duct would have 16 square inches, whereas a 4-inch diameter duct would have 12.57 square inches.

The NACA duct, diffuser and duct tubing should be located above the oil-cooler location. Remember to keep the duct length as short as possible, and use a NACA duct for each oil cooler. Avoid sudden changes in direction and diameter. The number of bends should be kept to a minimum and should have as large a bend radius as possible. Use a 1.5 or higher radius-to-diameter ratio. Sudden expansion or contractions should be avoided. Use smooth ducting or metal construction whenever possible. The ducting should use as large a cross section as practicable. Avoid tapers in the duct line, and avoid sharp bends—preferably have none at all.

Duct length is very important. The longer the duct length, the more pounds per square inch (psi) drop is lost in air



The typical NACA duct is an efficient way of drawing high-pressure air into an oil cooler with a minimum of added drag.

While still mainly air cooled through the cylinder fins, all common aero engines put a significant amount of heat into the oil.

density, air pressure, temperature, air mass lb/min and velocity. Adding bends to the ducting increases the psi drop.

When installing the diffuser to the oil cooler, use RTV to seal any gaps. You might be wondering, what is a diffuser? It is simply a transitioning point for the air flow leaving the duct to an opening, in this case at the oil cooler without getting technical as shown in Figure 2.

How Much Air-Mass Flow is Required?

Calculating how much air-mass flow is required involves two sets of variables, temperature and air-mass flow. The force convection equation becomes very lengthy, so if you are looking at the Figure 3 performance chart, you will notice that at 63 mph the required air temperature being exhausted out the back of the oil cooler is 150° F. As the air-mass flow increases—let's say to 220 mph—then the required exhaust temperature is 100° F for the proper heat rejection to cool the oil using dual oil coolers. Also notice in this chart the difference between using one versus two oil coolers and how much air flow is required to obtain proper heat rejection (air temperature being exhausted) from the oil cooler.

The Oil Gauge

What does the oil temperature gauge represent? A little white needle waves around saying, "Hi, I am here, and I'm working," with a white, green and red scale in the background (or the more sophisticated digital readout).

Oil temperature gauge scales normally range from 100° to 250° F, and some go as high as 300° F. The normal operating range (the green arc) on aircraft engines varies from 100° to 150° F on the low end, to 240° to 245° F on the high end of the scale. The oil flowing from the engine is 165° to 230° F to the oil cooler and 190° to 210° F returning to the engine, according to Lycoming's engine run-in test limits specification sheet.

But installation is important. The oil temperature probe for the Lycoming IO-360-A (like most Lycomings) is located where the cooled oil returns from the cooler back into the engine, and this does not give an accurate reading. The best location for the oil temperature probe on this engine would be at the front top, either at the 10 or 2 o'clock position. There is a boss location off of the engine centerline that is the highest oil temperature position of the engine block. The "Effects of Oil Temperature" Table shows why knowing oil temperature is so valuable and what the oil temperature scale actually indicates.

Oil above 200° F operating temperature will not last as long, because oxidation doubles for every 18° F increase in temperature. For example, at 245° F, the oil is oxidizing eight times faster than it would at 200° F. When oil oxidizes, two things happen: Viscosity breaks down, and then oil turns acidic. This can corrode the very engine parts the oil is meant to protect.

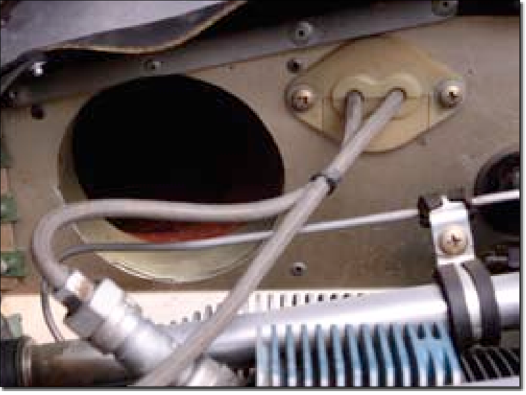
The oil temperature gauge and oil pressure gauge work hand in hand. If the oil temperature is low, the oil pressure will be high, because the oil is thicker and the engine oil pump is working harder, which puts additional stress on the engine. If the oil temperature is high, oil pressure will be lower, because the oil is thinner, and the engine oil pump does not have to work as hard.

Let's throw in outside air temperature (OAT). As the OAT goes up, so does the oil temperature and vice versa. However, remember that oil pressure is a variable, but not the oil flow (gallons per minute produced by the engine oil pump).

Clearly, your engine has a range of oil temps that are ideal for long life. It behooves you to design the cooling system to keep them there. —*N.E.*

Effects of Oil Temperatures on the Engine

Oil Temperature in the Engine	Effects
100° F to 150° F	Minimum limit (white line) on oil temperature gauge.
Below 170° F	Causes wear on internal engine components. Moisture will not evaporate in the oil. Low temperatures are just as harmful as high temperatures due to the buildup of water and acids within the oil system, which cause rust and corrosion of internal engine components.
180° F to 200° F	Ideal operating range.
210° F	An oil cooler is required when the oil is operating over this temperature in the engine.
212° F	Somewhere in the oil circulation of the engine, the oil temperature must be above this temperature in order for evaporation of water from the engine to occur. 180° F to 190° F gauge temperature.
220° F and above	Oil rapidly loses its ability to lubricate and cool, causing accelerated fatigue and premature component failure. In other words, this reduces the engine life.
240° F	Varnish forms (burning the oil onto the engine's internal parts).
240° to 245° F	Maximum limit (red line) on oil temperature gauge.
260° F to 295° F	Seals harden.
315° F	Seals burn out.
350° F	Bearing material softens.
450° F to 620° F	Bearing material melts.
500° F	Flashpoint of Aeroshell W100 50w oil. At this point the engine has probably seized, and you will start caring with a great deal of money.



For remote-mounted oil coolers, you'll need a pickoff point; here it's just ahead of the right rear cylinder. In this installation, that cylinder runs a bit warmer than its brethren on the other side of the crankshaft.

A 4-inch-diameter duct will require less air-mass flow for the proper heat rejection to cool the oil. The bigger the duct diameter, the more air-mass flow over the oil cooler surface area is cooled. If there is not enough airflow through the duct, increase the air-mass flow with a bigger duct size.

There are several ways to check for air-mass flow, one of which is using an air-mass flow indicator to be totally accurate; the indicator can cost several hundred dollars. The inexpensive way to check if the installation is correct is to calibrate the oil-temperature gauge on the instrument panel. Include graduation marks for different temperature readings, and fly the airplane to see if the oil temperature is at the correct reading at different outside air temperatures. Another possibility would be to install an airspeed indicator system in front of the oil cooler and a temperature gauge behind the oil cooler. Using the graph in Figure 3 to determine the correct airspeed versus temperature output would also give you a good indication of whether the installation is correctly backed up by the oil-temperature gauge reading.

In the end, you are responsible for ensuring that the oil cooling system is adequate. Understanding the engine's requirements—a way of double-checking that the kit manufacturer has recommended the right oil cooler—is the first part, followed by creating an installation that makes the most of the chosen cooler's capacity. Select wisely, install properly, and high oil temps should not be a problem for you. ✢